Chemical Fume Hood Safety

Protecting the Health of Laboratory Workers

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Abstract

A laboratory fume hood is a three-sided enclosure with an adjustable front opening. It is designed to capture, contain and exhaust the fumes generated inside its enclosure. Because inhalation of volatile chemicals constitutes a significant hazard to laboratory workers, fume hoods operate as a principle safety devise in a laboratory setting. Fume hoods also constitute the largest source of energy consumption within a laboratory. By exhausting laboratory air, fume hoods transport much of the laboratory's conditioned air to the building's exterior. The Lawrence Berkeley National Laboratory (LBNL) has developed a low-flow fume hood that exhausts less air than conventional hoods. This design allows nearly a 70 percent energy savings while at the same time enhancing laboratory worker safety. However, the LBNL hood does not meet the performance standard set by many regulatory organizations, a face velocity of about 100 feet per minute (fpm). Face velocity is the speed air enters the face opening of a laboratory hood. Because the LBNL low-flow design exhausts less air, there is a significant reduction in the speed at which air enters the hood opening. Consequently the LBNL hood has a greatly reduced face velocity over conventional designs. This paper looks at the policy barriers to moving the LBNL hood into the market place and identifies solutions to make the use of the low-flow hood possible.

Introduction

Several governmental and industry organizations have adopted fume hood safety standards. These standards are designed to measure a fume hood's ability to contain fumes. They are based the velocity at which laboratory air enters a fume hood's face opening, i.e. face velocity. The intent of these standards is to designate face velocities that are high enough to contain fumes but not so high as to cause air turbulence between a hood's face and a worker standing at the hood's face. Below is a list of some standards organizations and the face velocities they require:

OSHA (Federal Occupational Safety and Health Administration)

Appendix A recommends, "...airflow into and within the hood should not be excessively turbulent...; hood face velocity should be adequate (typically 60-100 lfm)..."

Cal/OSHA (California Occupational Safety and Health Administration)

California Title 8, 5154.1 requires 100 linear feet per minute with a minimum 70fpm at any one point, except for hoods with carcinogens, which require 150fpm and a minimum of 125fpm.

National Research Council

Prudent Practices in the Laboratory, Handling and Disposal of Chemicals, recommends face velocities between 80 and 100fpm. 120fpm is recommended for substances with very high toxicity or where outside influences adversely influence hood performance. Face velocities approaching or exceeding 150fpm should not be used.

NFPA (National Fire and Protection Agency)

Section 6-4.5 states, "Face velocities of 0.4 m/sec to 0.6 m/sec (80 fpm to 120 fpm) generally provide containment if the hood location requirements and laboratory ventilation criteria of this standard are met."

ANSI/AIHA (American National Standards Institute / American Industrial Hygiene Association)

Standard *Z9.5-1992* Section 5.7 requires that, "Each hood shall maintain an average face velocity of 80-120 fpm with no face velocity measurement more than plus or minus 20% of the average."

S.E.F.A (Scientific Equipment & Furniture Association)

SEFA 1.2-1996 Section 5.2, "Government codes, rules and regulations may require specific face velocities. A fume hood face velocity of 100 fpm is considered acceptable in standard practice. In certain situations face velocity of up to 125 fpm or as low as 75 fpm may be acceptable to meet required capture velocity of the fume hood."

N.I.H. (National Institutes of Health)

National Institutes of Health Fume Hood Containment Testing states, "Face velocity measurements shall meet an air velocity profile of 100 fpm plus or minus 10 fpm with the sash fully open."

NIOSH (National Institute for Occupational Safety and Health)

NIOSH recommends face velocities of 100 to 150 fpm

Knutson, G. *Fume Hood 2000, Laboratory Hood Testing and Evaluation*. Presentation given at the Fume Hoods 2000 Seminar. April 21, 1999

ACGIH (American Conference of Governmental Industrial Hygienists)

Industrial Ventilation A Manual of Recommended Practice recommends 80 - 100 fpm face velocity with a full open sash depending on quality of supply air distribution and uniformity of face velocity.

Face velocity has been accepted as an adequate measure of a fume hood's performance for many decades. It is such an established method that it is the only performance standard adopted by many of the organizations listed above.

ASHRAE, The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, has created the *ASHRAE 110-1995 Method of Testing Performance of Laboratory Fume Hoods*[i], a protocol for fume hood testing. This protocol does not specify a performance level fume hoods should meet; it simply provides a thorough protocol for fume hood performance testing.

The ASHRAE 110 is a three part test that includes measurements of face velocity, air-flow visualization, and tracer gas containment. This comprehensive test protocol goes beyond face velocity measurement to test a fume hood's ability to contain and exhaust fumes. The air flow visualization test generates smoke streams at designated points within a fume hood. It provides a visual understanding of air flow currents that exist within a hood. The tracer gas containment test releases a tracer gas at a prescribed locations in a hood. A mannequin is positioned at the hood's face with a monitoring device affixed in its breathing zone. The monitoring device tests the tracer gas concentration outside the hood.

Face velocity is just one of the three tests called for in the ASHRAE 110; yet face velocity is often the only test performed once a fume hood is installed. There are several reasons for this. The full ASHRAE 110 is expensive. The cost of the recommended tracer gas, sulfur hexafluoride, and the equipment that tests for this gas can approach $20,000. The full test is also quite time consuming to complete. It can take a couple hours to test each hood. Large organizations with hundreds of hoods could need months to test them. Face velocity is also the only item required to be tested by most regulatory organizations. For these reasons, face velocity tests are often the only tests performed on installed fume hoods.

Many studies[1] regarding fume hood safety have indicated that face velocity is not the best measure of a fume hood's ability to contain hazardous fumes. They have shown that factors other than the speed at which air enters the fume hood opening are significant in determining a fume hood's ability to contain hazardous fumes. Some of these significant factors include:

- The location of the fume hood in the laboratory setting.
- The laboratory’s supply air distribution.
- The amount of equipment stored in the hood.

Some studies[1] have shown that a significant number of hoods are able to meet face velocity tests but are not able to pass containment tests such as the ASHRAE 110. Many of these studies[1] recommend that face velocity tests be replaced with containment testing in order to improve laboratory worker safety.

Results

Factors other than the velocity at which air enters a fume hood opening are important in determining the fume hood’s ability to contain. The following is a list of reports that support performance-based, fume hood containment tests over face velocity measurements.

> “The ability of the laboratory fume hood to capture and contain hazardous fumes and vapors is often equated to its face velocity. Although average face velocity and containment efficiency are related under ideal conditions, they are not the same.”(Hitchings)[ii]

> “Face velocity testing and maintaining a specific face velocity does not assure fume hood containment.”(Hitchings)[i]

> “If traditional face velocity testing alone were used to determine performance, more than half of the hoods exhibiting high leakage and, therefore, high exposure potential, would have been overlooked. This case study and evidence from several thousand additional ASHRAE 110 tests performed on other fume hoods show that face velocity alone is a *very* poor indicator of fume hood containment.”(Hitchings)[iii]

> “Tests prescribed in the ANSI/ASHRAE 110 *Method of Testing Performance of Laboratory Fume Hoods* (ASHRAE 110) standard including low- and high-volume smoke tests, face velocity tests, and tracer gas containment

[1] See literature cited section at end of report.

tests indicated that many of the hoods did not meet industry consensus standards for containment (0.1 ppm), yet met industry recommended face velocity specifications (80-120 ft/min)."(Maupin)[iv]

"The results of the study indicate that average face velocity may not be a reliable indicator of hood performance as escape was detected at some hoods operating at face velocities between 80fpm and 150fpm. Conversely, satisfactory hood containment was found in some cases were hoods were operating at average face velocities less than 80fpm and greater than 150fpm. The study concludes that reliance on average face velocity as the sole criterion for acceptable hood performance is overly simplistic and potentially misleading."(Smith)[v]

"Qualitative assessments with smoke under different working conditions indicated poor smoke capture and containment of 20 percent of the hoods with face velocities within the 85 to 130 ft/min range…"(Volin, et al.)[vi]

"Upon completion of this research, it became evident that current face velocity standards for rating hood performance are inadequate."(Woodrow)[vii]

"No correlation between average face velocity and containment was observed."(Greenly, et al.)[viii]

"Face Velocities established in the past by the fume hood industry may not necessarily be a direct indication of good containment. Tracer gas tests have proven this."(Wisconsin)[ix]

"Face velocity alone is inadequate to describe hood performance and is not more important than supply air distribution."(AIHA)[x]

"This standard does not establish a standard for face velocity because of the importance of other parameters and the existance of an applicable performance test (ANSI/ASHRAE 110)."(AIHA)[x]

"Measurement of hood face velocity is a handy way to determine that design air flow rates are being maintained; however, it is not a direct measure of a hood's ability to provide containment in spite of the fact that regulatory and professional organizations specify average face velocity as an operating criterion."(DiBerdinis et al.)[xi]

Most organizations have limited their fume hood testing to face velocity in spite of the superiority of a full ASHRAE 110 evaluation. Industry and Government organizations have stipulated face velocities as a measure of a fume hood's performance for decades. Familiarity with this method of testing and problems with the ASHRAE 110 test have left face velocity the method most commonly used for fume hood testing. Below are some of the problems confronted when performing ASHRAE 110 tests:

- *Time*: A full ASHRAE 110 test can take a couple hours or more to complete per hood. Organizations with only a few fume hoods may not find this a problem. Organizations with many fume hoods could require months to complete a full fume hood inspection.

- *Expense*: Sulfur hexafluoride is an expensive gas, costing a few thousand dollars per canister. The detection equipment available for sampling this gas can exceed fifteen thousand dollars. Sulfur hexafluoride makes for an expensive test.

- *Accuracy*: The ASHRAE 110 tracer gas test requires an exact measurement of the sulfur hexafluoride concentration present in the test mannequin's breathing zone. Two instruments are widely used to test for the concentration of sulfur hexafluoride, the Foxboro Miran 1A and the ITI Leakmeter. Neither of these instruments is designed to provide accurate measurements of the sulfur hexafluoride concentrations typically present in the mannequin's breathing zone (~ 0.025 ppm to 0.10 ppm). They are both designed to ascertain the mere presence of the gas.

A fume hood's function is to contain the vapors, gases and particulates generated inside its enclosure; therefore, the best fume hood test is one that tests its *ability* to contain. A good containment test releases a gas at a controlled rate within the hood while measuring for gas leakage outside the hood. This test methodology best approximates the conditions under which a fume hood operates.

Under section 4.1.2 of the ASHRAE 110 standard, another tracer gas may be substituted for sulfur hexafluoride provided, "…the standard tracer gas is deleterious to materials in the hood or laboratory or if there would be significant interference in the detection of the tracer gas." Also, the equipment used for the detection of the substituted gas must, "provide greater sensitivity than required for the presumed control level of the hood being tested."[xii] This section allows a substitute gas to be used so long as it can be tested as precisely as sulfur hexafluoride.

An acceptable gas for testing fume hood containment must be non-toxic, non-explosive and relatively inexpensive. It should also approximate the density of ambient laboratory air. If it is much lighter than air, its natural inclination would be to rise up into the hoods ductwork. If it is much heavier than air, its inclination would be to sink to the hood’s bench top.

Sulfur Hexafluoride is a very heavy gas, much heavier than air. It is also quite expensive. The main advantages of using this gas is that it is non-flamable and non-toxic.

Helium is an extremely light gas, much lighter than air. It is, however, widely available and relatively inexpensive. It is non-flamable and non-toxic.

Ethylene has nearly the same weight as air. It is widely available and less expensive than sulfur hexafluoride. Ethylene is a combustible gas, however, only in concentrations much higher than would be required for fume hood testing. It is also non-toxic.

Methyl Acetylene is slightly heavier than air. The exposure limit for methyl acetylene is 1000ppm, which is the same as for sulfur hexafuoride. It is an explosive gas and not as widely available as ethylene, carbon dioxide, or helium.

Carbon Dioxide is slightly heavier than air. It is widely available and quite inexpensive. It is also non-flamable and non-toxic. The chief drawback to its use is the already high background concentrations.

Many other gases could be used to test fume hood containment. However, few gases have allowable exposure limits as high as 1000 ppm, approximate the required density, and are non-explosive. All of the above gases have allowable exposure levels of 1000 ppm or greater.

Few instruments are able to precisely measure concentrations of gases under 1 ppm. Those that can tend to be of high cost, such as gas chromatographs. The ITI Leakmeter and the Foxboro Miran are currently used to test for sulfur hexafluiride and cost over $15,000. The following is a list of correspondence with various companies that manufacture equipment for the detection of gas leaks. The question I posed to these companies was, *"Do you have an instrument that measures for ethylene gas, sulfur hexafluoride gas, or methyl acetylene gas in units under 0.1ppm? If so, what is the cost of the instrument?"*

John B. Lipsky, President Quadrex Corporation
"We can offer you a portable gas chromatograph (Model 8610C GC) configured with : Gas Sampling Valve plumbed with dual loops Heated valve oven ECD detector for SF6 (this can go down to 10PPT). Mole sieve column to separate SF6 FID detector for ethylene and acetylene. Heated adsorbent trap to concentrate ethylene and acetylene (with concentration you should be able to see below 0.1ppm). Haysep column to separate C2H4 and C2H2 Second EPC for H2 carrier gas used with ECD. A GC configured as above will be approximately $17,000.00."

Duncan Johns with Ion Science
"Yes we have several instruments that can detect these. Ethylene we can detect down to ppb in our hand held PhoCheck instrument. We can detect SF6 with two instruments one the general purpose leak detector GasCheck which will detect it down to a few hundred PPM and the other a dedicated GasCheck SF6 machine. which detect it down to 0.1ppm. The GasCheck will probably detect Methyl acetylene I don't however know the response but it is likely to be in the hundreds of PPM, the PhoCheck will I think detect Methyl acetylene, I'll discuss this with the chemists on Monday as it isn't on my gas table, it does it will be in the ppb range, but it may require a special

UV lamp as this is the principle the instrument uses." Phocheck 5000 is listed for $4,700. Gas Check SF6 begins at $14,995.

Betty Osmanoglu Crowcon Detection Instruments
"Regarding your request for gas detection products, Crowcon does have a product that can detect concentrations of ethylene and methyl acetylene as low as 10 ppb. We have nothing available to detect sulfur hexafluoride. The product that we can offer is the Viper and is a PID. " The Viper PID sells for $3,995.

Christine A. Clancy Customer Service Supervisor (thermalei)
"We do not manufacture portable instruments to measure Sulfur Hexafluoride or Ethylene. However, we do manufacture a portable instrument to measure Methyl Acetylene. It's called the Model 580B it's is on our webpage if you would like information on it. The base price is $3,740.00"

The following list of companies that were unable to meet the specifications required:

GfG Gesellschaft fuer Geraetebau
BW Technologies Ltd.
General Monitors, Inc.
Technical Services Supervisor Gas Tech, Inc.
Assay Technologies:
Jandnent
Vacuum Technology Incorporated
Amgas
Manning Systems, Inc.
Gas Tech, Inc.

Conclusions

It has been demonstrated in the “Results” section of this paper that many research projects have been conducted into the safety of laboratory fume hoods. These reports are united in their support for containment testing over face velocity testing in the commissioning of laboratory hoods. The authors argue that simple face velocity measurements do not reflect a fume hood’s ability to contain hazardous fumes.

A thorough and precise test methodology that reflects a fume hood’s containment ability is needed. The *ASHRAE 110 Method of Testing Performance of Laboratory Fume Hoods* provides such a methodology; however, this protocol is time consuming and expensive.

Additional research needs to be completed to determine suitable replacement gases for sulfur hexafluoride and suitable detection equipment for these replacement gases. The alternative gases must be readily available, inexpensive, non-explosive, non-toxic, and approximate the density of ambient air. Suitable detection equipment must be easy to use, portable, inexpensive and accurate in the range of 0.025 to 0.1 ppm. Promising detection equipment that meets these qualifications include photo-ionization devices and portable gas chromatographs.

If suitable tracer gases and detection equipment are adopted, the expense and complexity of containment testing will be lessened. This will enable greater use of containment testing in the field and greatly enhance the safety of laboratory workers.

In addition to the fine-tuning of the ASHRAE 110 protocol, it is also important to update some of the standards that have made face velocity testing so widely used. These standards have also made the market penetration of new fume hood technologies more difficult. In the case of the LBNL fume hood, face velocity standards present a significant barrier to market penetration.

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